Internship Report

Submitted by:

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(1st year BS-MS Dual Degree programme)

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IISER KOLKATA

Assessment of MetOcean conditions and Shoreline Change during *Lehar* cyclone.

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INCOIS

DECLARATION

I **Sudeep Das** bearing Roll Number- **15MS031**, of **Indian Institute of Science Education And research (IISER), Kolkata** do hereby declare that the project entitled on "**Assessment of MetOcean conditions and Shoreline Change during Lehar cyclone.**" , at **Indian National Centre for Ocean Information Services (INCOIS)** is an authentic work done by me under the guidance **of Dr Prakash Chandra Mohanty**.

I further declare that this work has not been submitted completely or partially earlier to any other Institution or University for any degree, diploma, fellowship or any other similar title of recognition.

Place: ESSO-INCOIS, Hyderabad

Date: 1st July, 2016

Sudeep Das

1st year BS-Ms student

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741246

CERTIFICATE

This is to certify that the project work entitled, **"Assessment of MetOcean conditions and Shoreline Change during Lehar cyclone."** submitted by **Mr. Sudeep Das,** a student of BS-MS Dual Degree programme in **Indian Institute of Science Education And research (IISER), Kolkata**, is a record of bonafide work carried out by him in our organization, Indian National Centre for Ocean Information Services (INCOIS), Hyderabad

This project was done under my guidance and supervision and was found worthy of acceptance.

Dr Prakash Chandra Mohanty

Project Guide

Project Scientist-B, ASG

ESSO-INCOIS

ACKNOWLEDGEMENT

I wish to give special thanks to **Dr. S S C Shenoi**, Director of INCOIS, Hyderabad for allowing me to undertake the project and providing me a good environment to work.

I also wish to give my special thanks to **Dr. Pradipta Purkayastha**, Dean of Academic Affairs for helping me and giving me this opportunity.

I also give my thanks to **Dr Francis P A**, Students coordinator for providing me suitable conditions to work and making my stay at INCOIS memorable.

I express my sincere gratitude to my guide **Dr Prakash Chandra Mohanty** for accepting me as a student and giving me continuous support and guidance during this internship. He gave me necessary knowledge and experience required for this work.

I would thank Mr Sidhartha Sahoo and Mr Jithu, Scientific assistants in Knowledge Resource Centre for helping me in various formal and non-formal issues.

Last but not the least, my special thanks to my parents, my sister and all my friends for having faith in my efforts and their everlasting support which made me capable of choosing the best myself.

This work is an output of the blessings and good wishes of almighty and my elders as well as support, love and cooperation of all my near and dear ones.

(Sudeep Das)

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LIST OF ABBREVIATIONS

Chl	:	Chlorophyll
LH	:	Latent Heat
MLD	:	Mixed Layer Depth
PPT	:	Precipitation
SST	:	Sea Surface Temperature
SH	:	Sensible Heat
QA	:	Humidity
WS	:	Wind Speed
UR	:	Upper Right
UL	:	Upper Left
LR	:	Lower Right
LL	:	Lower Left

I. INTRODUCTION

i. Tropical Cyclones:

Tropical cyclones are massive and powerful circular storms which are characterized by low atmospheric pressure, high winds and heavy rain. This phenomena is given different names in different parts of the world. In western Pacific these are called typhoons, in Atlantic Ocean and eastern Pacific Ocean these are called Hurricanes and in the west Southern Pacific and the Indian Ocean, these are referred to as Tropical cyclones. In addition to strong winds and rain, tropical cyclones are also capable of generating high waves, damaging storm surge and even tornadoes. Generally coastal regions are more prone to hazards since tropical cyclones weaken on land due to loss of energy.

Every year during the late summer months (July-September in the Northern Hemisphere and January-March in the Southern Hemisphere), Cyclones strike regions as far apart as the Gulf coast of North America, northwestern Australia, and eastern India and Bangladesh.[1]

Every year, they cause considerable loss of life and do immense damage to property. However, tropical cyclones are essential features of the Earth's atmosphere, as they transfer heat and energy between the equator and the cooler regions nearer the poles.[2]

ii. Cyclone Lehar:

For this internship, we were assessing the cyclone *Lehar* (Hindi word for “wave”), a tropical cyclone which affected the Andaman and Nicobar Islands and the state of Andhra Pradesh in India. It was the second most intense cyclone of 2013 (the most intense being *Phailin*). It affected Southern India late in November 2013. This cyclone was classified as Category 1 by Saffir-Simpson scale and Very Severe Cyclonic Storm (VSCS) by the scale of Indian meteorological Department (IMD).

The origins of *Lehar* can be tracked back to an area of low pressure that formed in the South China Sea on 18 November. The system slowly drifted westwards and entered the Bay of Bengal, where it quickly consolidated into a depression on November 23. It moved west-northwest into an improving environment for further development before the system was named *Lehar* on November 24, after it had developed into a cyclonic storm and passed over the Andaman and Nicobar Islands into the Bay of Bengal. Moving along a generally west-northwestward path in the following days, the storm passed over an area having cooler waters and a moderate vertical wind shear. The storm's low-level circulation centre (LLCC) started losing its structure, triggering a weakening trend. Lehar rapidly weakened to a Depression on November 28 and its fully exposed LLCC made its second landfall over the coast of near Andhra Pradesh Machilipatnam. The same day, it was last noted as a well-marked low pressure area over Andhra Pradesh. Extensive preparation was done in the wake of the storm by the authorities of the coastal districts of Andhra Pradesh and Odisha, including the evacuation of 45,000 people in low-lying areas. The storm's rapid weakening before landfall led to no reported fatalities and minimal damage.[3]

iii. Shoreline Change Mapping

Shoreline changes induced by erosion and accretion are natural processes that take place over a range of time scales.They may occur in response to smaller scale events such as storms, tides and winds or large scale events such as sea level rise and tectonic movements.[4].The shoreline is one of the rapidly changing features of the coastal zones which is dynamic in nature.

The eastern coast of India is eroding severely due to landfalls of tropical cyclones every year. Generally the left side of the landfall is more affected since the wind and rainfall moves away from the shore.

II. STUDY FIELD

i. Scope of Study

The scope of the study is about different conditions which led to and prevailed during the cyclone. These factors include

- oceanic conditions such as sea surface temperature and mixed layer depth,
- heat fluxes such as latent and sensible heat,
- atmospheric conditions such as humidity, pressure, winds and precipitation
- chlorophyll content
- Shoreline change

ii. Need for study

Cyclones are natural phenomena which is both hazardous as well as important to the bio system. These affect mostly coastal regions. This phenomenon is studied by meteorologists as well as oceanographers around the world. Cyclones are studied for its characteristics, importance and vulnerability. In India we suffer at least four to six cyclones every year, mostly from Bay of Bengal.

The main objective of this report is to assess the basic conditions in air, sea and its interaction prior to and during a cyclone such as temperature, humidity, precipitation, heat fluxes etc along with its effect to the shore, such as erosion or accretion. This results in understanding the reasons to formation and effects of cyclone.

iii. Study Area

The areas used for study are the Bay of Bengal, the Andaman and Nicobar Islands and the central east coast of India.

The Bay of Bengal, the largest bay in the world, forms the northeastern part of the Indian Ocean. Roughly triangular, it is bordered mostly by India and Sri Lanka to the west, Bangladesh to the north, and Myanmar and the Andaman and Nicobar islands to the east. The Bay of Bengal occupies an area of 2,172,000 square kilometres (839,000 sq mi).[5]The Bay of Bengal, located in the northeast of the Indian Ocean, is responsible for the formation of some of the strongest and deadliest tropical cyclones in the world. The basin is abbreviated BOB by the India Meteorological Department (IMD), the official Regional Specialized Meteorological Centre of the basin.[17]

The Andaman and Nicobar Islands, one of the seven union territories of India, are a group of islands at the juncture of the Bay of Bengal and Andaman Sea. The territory's capital is the Andamanese town of Port Blair. The total land area of these islands is approximately 7,950 km^2 (3,070 sq mi). [6]

The area used for study of landfall includes the northern Coromandel coast and the south of the Northern Circars. This region consists of important places like Vishakhapatnam, Vijayawada and Nellore.

The following points are the reasons why Bay of Bengal is more susceptible to cyclones and this area was chosen:

- Since Bay of Bengal is between the Tropic of Cancer and the Equator, it gets a fair amount of heat and remains warm over long periods.
- A huge number of rivers flow into the Bay of Bengal, due to which the saline content is less and water becomes less dense but heats up easily.
- Apart from Depressions forming in Bay of Bengal, the remnants of typhoons from North-west Pacific towards west also power up in Bay of Bengal to form new powerful

cyclones.

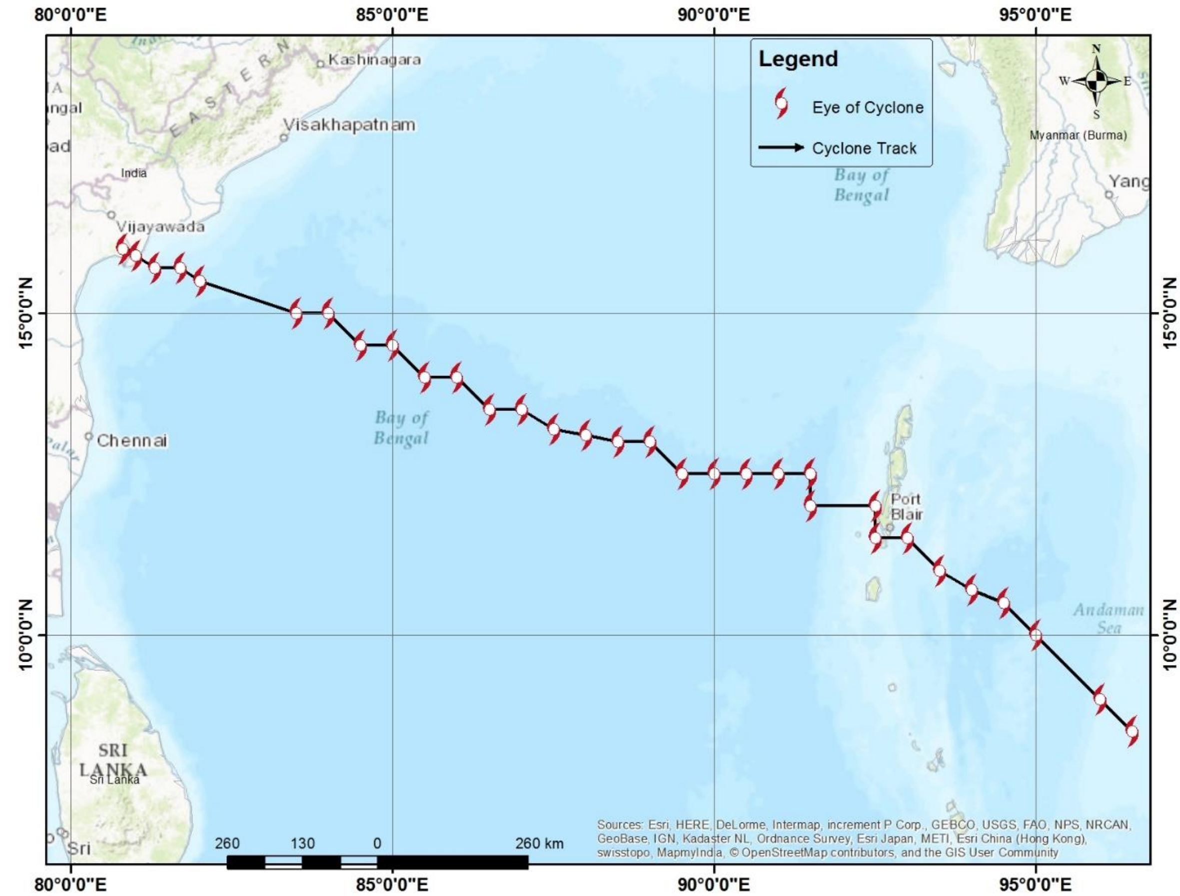


Figure 1: Track of cyclone Lehar

III. METHODS AND MATERIALS

i. DATA USED

Table 1: Summary table of Data used from sensors

DATA	**SENSOR/DATA SOURCE**	**RESOLUTIONS**	
		SPATIAL RESOLUTION	**TEMPORAL RESOLUTION**
Sea Surface Temperature	AVHRR/NOAA	0.25° × 0.25°	24:00 hrs
Latent Heat flux	OAFlux	1.0° × 1.0°	24:00 hrs
Sensible Heat flux	OAFlux	1.0° × 1.0°	24:00 hrs
Wind	ECMWF	0.25° × 0.25°	06:00 hrs
Humidity	OAFlux	1.0° × 1.0°	24:00 hrs
Precipitation	TMI/TRMM	0.25° × 0.25°	03:00 hrs
Chlorophyll	Modis Aqua/NASA	5km × 5km	24:00 hrs
Mixed Layer Depth	ARGO/INCOIS	1.0° × 1.0°	240:00 hrs
Shoreline	LANDSAT/USGS	30m × 30m	variable

AVHRR

Advanced very-high-resolution radiometer (AVHRR) instruments are a type of space-borne sensor that measure the reflectance of the Earth in five spectral bands that are relatively wide by today's standards. Most AVHRR instruments are or have been carried by the National Oceanic and Atmospheric Administration (NOAA) family of polar orbiting platforms (POES). The first two are centred on the red (0.6 micrometres, 500 THz) and near-infrared(0.9 micrometres, 300 THz) regions, the third one is located around 3.5 micrometres, and the last two sample the thermal radiation emitted by the planet, around 11 and 12 micrometres, respectively. The NOAA satellite has equator crossing times of 0730 and 1930 local solar time.[7] This data was used for sea surface temperature data.

ECMWF

The European Centre for Medium-Range Weather Forecasts, ECMWF, is an independent intergovernmental organization supported by most of the nations of Europe and is based at Shinfield Park, Reading, United Kingdom. It operates one of the largest supercomputer complexes in Europe and the world's largest archive of numerical weather prediction data.[8] Data for wind was taken from here.

OAFlux

The OAFlux project is an ongoing research and development project for global air-sea fluxes. The project is committed to developing enhanced global estimates of air-sea fluxes of heat, fresh water, and momentum, with a goal of establishing a one-stop source for global ocean surface forcing datasets that serves the needs of the ocean and climate research community. The project currently provides global time series of ocean latent and sensible heat fluxes, ocean evaporation, and flux-related surface meteorology from 1958 to present, and maintains a twice-per-year update of the datasets. Global analysis of satellite-based high-resolution ocean surface vector wind fields has also been developed for the period from July 1987 onward. All data sets are freely available from the project FTP site.[9] Data for latent and sensible heat fluxes were taken from here.

Aqua MODIS

The moderate-resolution imaging spectroradiometer (MODIS) is a payload scientific instrument built by Santa Barbara Remote Sensing that was launched into Earth orbit by NASA in 1999 on board the Terra (EOS AM) Satellite, and in 2002 on board the Aqua (EOS PM) satellite. The instruments capture data in 36 spectral bands ranging in wavelength from 0.4 µm to 14.4 µm and at varying spatial resolutions (2 bands at 250 m, 5 bands at 500 m and 29 bands at 1 km). Together the instruments image the entire Earth every 1 to 2 days. They are designed to provide measurements in large-scale global dynamics including changes in Earth's cloud cover, radiation budget and processes occurring in the oceans, on land, and in the lower atmosphere. MODIS utilizes four on-board calibrators in addition to the space view in order to provide in-flight calibration: solar diffuser (SD), solar diffuser stability monitor (SDSM), spectral radiometric calibration assembly (SRCA), and a v-groove black body. MODIS has used the marine optical buoy for vicarious calibration. MODIS is succeeded by the VIIRS instrument on board the Suomi NPP satellite launched in 2011 and future Joint Polar Satellite System (JPSS) satellites.[10] Chlorophyll content data was taken from this sensor.

TMI

The TRMM Microwave Imager (TMI) was a passive microwave sensor designed to provide quantitative rainfall information over a wide swath under the TRMM satellite. By carefully measuring the minute amounts of microwave energy emitted by the Earth and its atmosphere. TMI was able to quantify the water vapour, the cloud water, and the rainfall intensity in the atmosphere. It was a relatively small instrument that consumed little power. This, combined with the wide swath and the quantitative information regarding rainfall made TMI the "workhorse" of the rain-measuring package on Tropical Rainfall Measuring Mission.[11] This sensor provided data for precipitation.

ARGO

Argo float buoys provided the data for mixed layer depth (MLD). Argo is a system for observing temperature, salinity, and currents in the Earth's oceans which has been operational since the early 2000s. The real-time data it provides is used in climate and oceanographic research.[12]

BEST TRACK

The best track data was taken from archives of Regional Specialized Meteorological Centre for Tropical Cyclones over North Indian Ocean by Indian Meteorological Department.

LANDSAT 8

Landsat is an American Earth observation satellite launched on February 11, 2013. Originally called the Landsat Data Continuity Mission (LDCM), it is collaboration between NASA and USGS. It utilizes two sensor payloads, the Operational Land Imager (OLI) and the Thermal InfraRed Sensor (TIRS). It operates in the visible, near-infrared, short wave infrared and thermal infrared spectrums. I captures 400 scenes a day.

Table 2: Landsat bands used for mapping [13]

Band 1 – coastal aerosol	0.43 - 0.45	coastal and aerosol studies
Band 2 – blue	0.45 - 0.51	Bathymetric mapping, distinguishing soil from vegetation and deciduous from coniferous vegetation
Band 3 - green	0.53 - 0.59	Emphasizes peak vegetation, which is useful for assessing plant vigour
Band 4 - red	0.64 - 0.67	Discriminates vegetation slopes
Band 5 - Near Infrared (NIR)	0.85-0.88	Emphasizes biomass content and shorelines

ii. SOFTWARES USED

FERRET

Ferret is an interactive computer visualization and analysis environment designed to meet the needs of oceanographers and meteorologists analyzing large and complex gridded data sets. It runs on recent UNIX and Mac systems, using X windows for display. PyFerret, introduced in 2012, is a Python module wrapping Ferret. The pyferret module provides Python functions so Python users can easily take advantage of Ferret's abilities to retrieve, manipulate, visualize, and save data. Ferret was developed by the Thermal Modelling and Analysis Project (TMAP) at PMEL in Seattle to analyze the outputs of its numerical ocean models and compare them with gridded, observational data. The model data sets are generally multi-gigabyte in size with mixed multi-dimensional variables defined on staggered grids. Ferret offers a Mathematica-like approach to analysis; new variables may be defined interactively as mathematical expressions involving data set variables. Calculations may be applied over arbitrarily shaped regions. Fully documented graphics are produced with a single command. Ferret is widely used in the oceanographic community to analyze data and create publication quality graphics.[14]

ArcGIS

ArcGIS is a geographic information system (GIS) for working with maps and geographic information. It is used for: creating and using maps; compiling geographic data; analyzing mapped information; sharing and discovering geographic information; using maps and geographic information in a range of applications; and managing geographic information in a database. The system provides an infrastructure for making maps and geographic information available throughout an organization, across a community, and openly on the Web.[15]

DSAS

This software computes the rate of shoreline change using historical shoreline positions represented in a GIS. The software can also be used to compute rates of change for other boundary change issues that incorporate a clearly identified feature position at discrete times. Requires ArcGIS Desktop 10.x and MATLAB component runtime library utility (free download).[16]

iii. METHODOLOGY

Table 3: Methodology of studying MetOcean conditions

- Required data extracted from the sensors
- Data filled in using ferret and analysed against time
- For more analysis data plotted against time for specific locations
- Plots analysed and results post processed.

Table 4: Methodology of studying Shoreline change

- Landsat 8 image loaded
- Rastered composition of bands
- Digitization of shorelines
- Creation of a baseline
- EPR measured using DSAS tool
- Transect studied
- Overlaid estimation to estimated shoreline erosion and accretion.
- Created shoreline change map and statistics.

Chapter- IV

IV. RESULTS AND DISCUSSION

i. ATMOSPHERIC CONDITIONS:

Every cyclone is born as a depression in the ocean. The pressure starts to fall gradually as the cyclone strengthens itself. Severe tropical cyclones have pressure decreased up to 990 milibars in the Indian Ocean. Some extreme cyclones can reach 940 milibars. However, the pressure of ‘super typhoons’ in the western Pacific can go as low as 880 milibars. Cyclone Lehar reached the lowest pressure of 980 milibars.

This figure 2 shows that a depression was created on 22nd November 2013 which showed a lowest value of 1010 milibars. Later the pressure dropped up to 962 milibars and moved along with the cyclone eye. After the landfall, the pressure increased and became normal. To understand the conditions in detail, graphs were plotted at the site of the origin, centre of the track and at the point of landfall. The results are as follows.

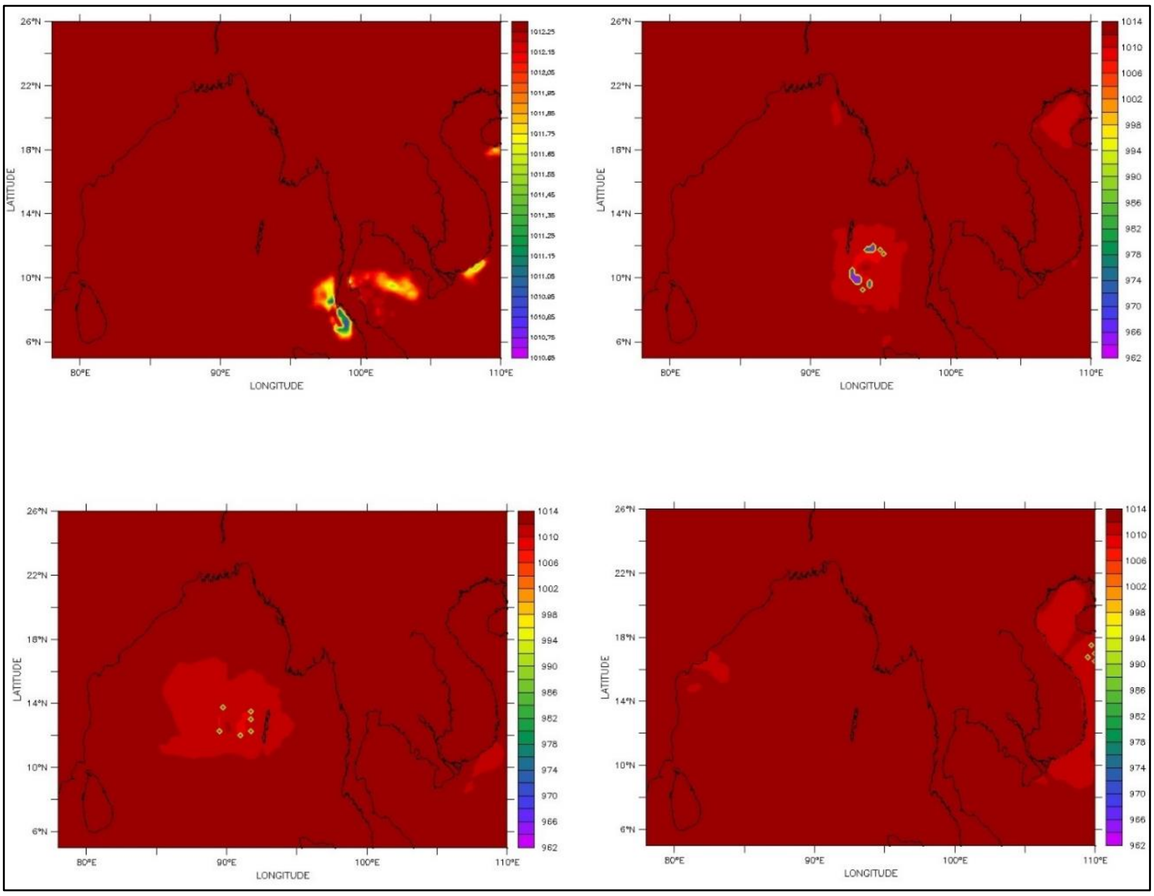


Figure 2: Atmospheric pressure on 22nd (UL), 24th (UR), 26th (LL) and 28th (LR) November.

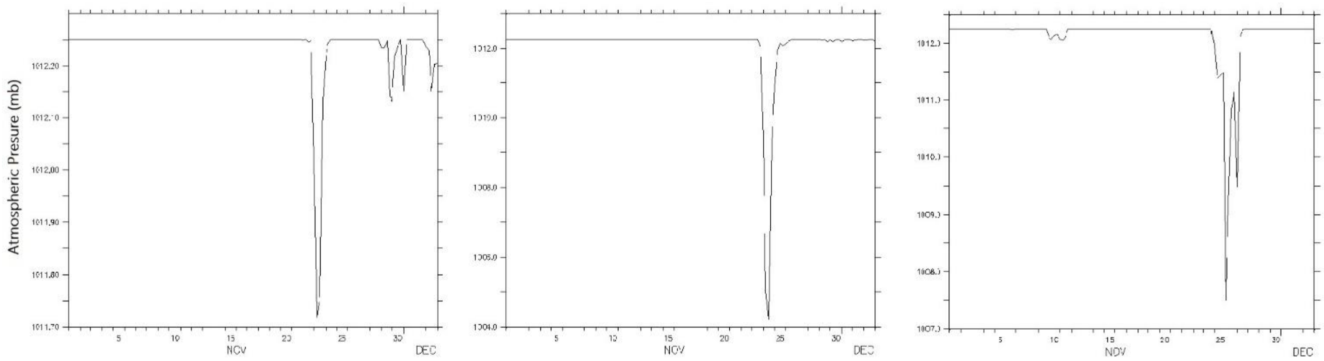


Figure 3: Atmospheric pressure plots for points on the origin (L), point of maximum strength (M) and point of landfall (R)

Generally a cyclone is formed when an area of low pressure is created. The plots in figure 3 show that when cyclone originates, the pressure decreases rapidly. This low pressure is carried towards land and while propagating, it gains more power and becomes lower. After landfall, the power of the cyclone dissipates and pressure tends to become normal.

The potential energy of the cyclone is directly proportional to pressure. So the potential energy gets converted to kinetic energy by the wind flowing into the area of low pressure. Lesser the pressure, greater is the energy it possesses and therefore the wind speed is greater in these places.

As the Earth rotates, a pseudo force called Coriolis force is created due to the angular velocity of the earth. This deflects objects to the left in Northern hemisphere, causing counter clockwise rotation. The cyclones cover a large amount of area, hence they have a low Rossby number, and therefore rotation is very important causing high winds.

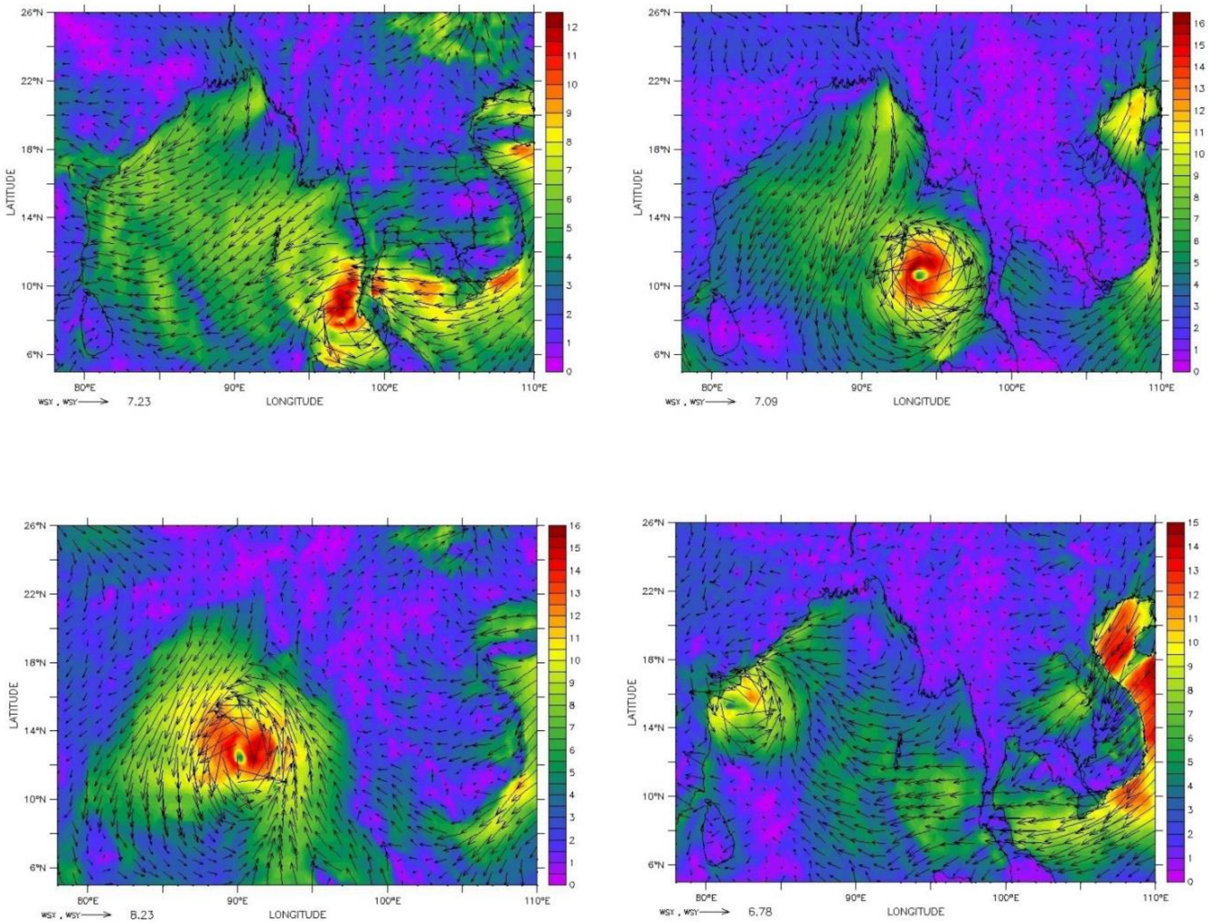


Figure 4: Wind speeds and directions on 22nd (UL), 24th (UR), 26th (LL) and 28th (LR) November

On 26th November, 2013 at 1800 hrs, the wind speed reached a maximum of 75 knots (nearly 140kph). This was when the eye of the cyclone was around 480 km away from the shore. Therefore this did not turn to much harm.

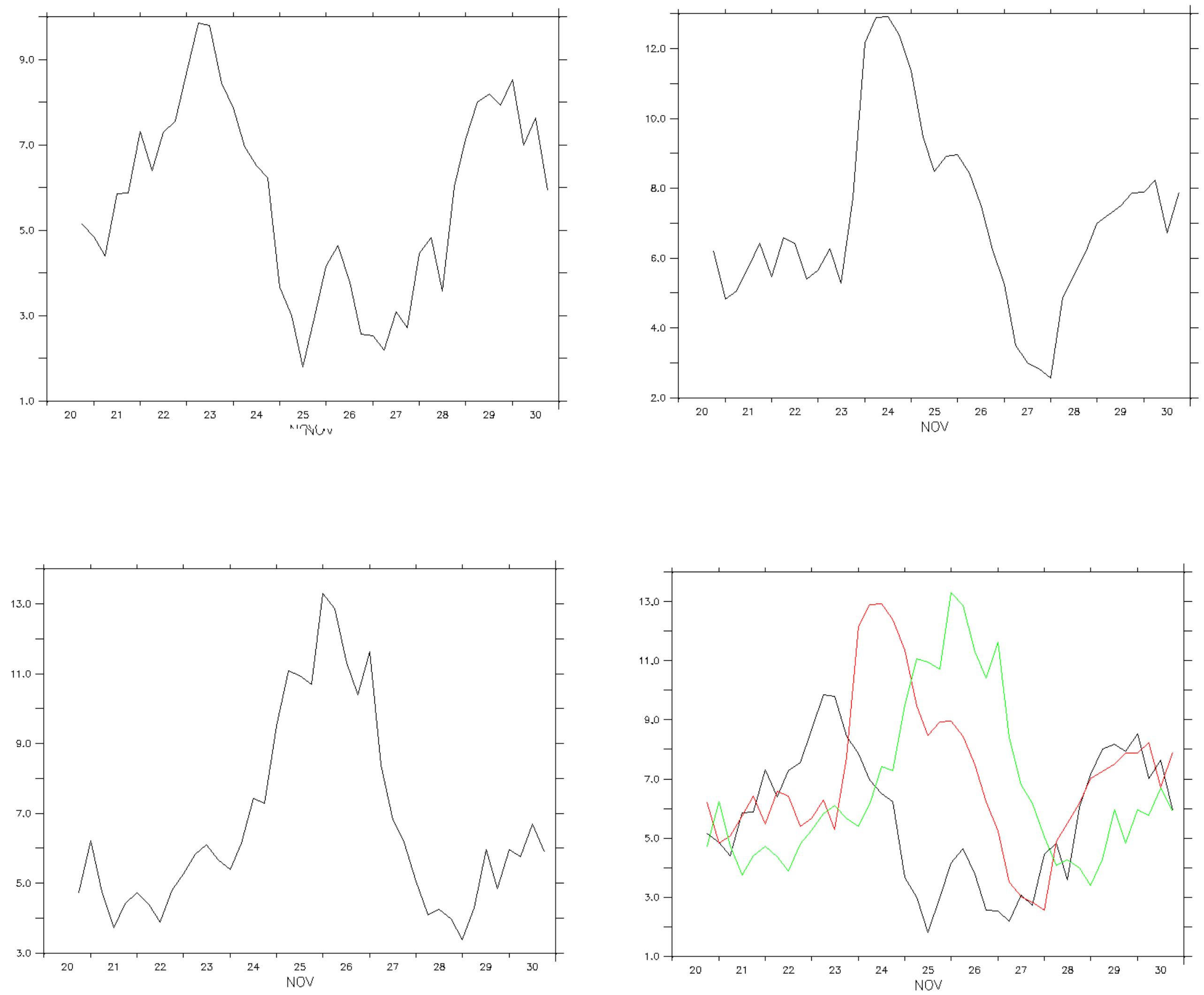


Figure 5: Wind speed plots for points on the origin (UL), point of maximum strength (UR) and point of landfall (LL), and the composite of the three graphs (LR).

The first three plots of figure 5 shows variations of wind speed on different places of the cyclone influence. The final graph shows that the maximum speed increased as the cyclone moved along the track bringing to the conclusion that the cyclone gained energy while travelling. After landfall, the wind speed decreased rapidly since the cyclone was losing power and the wind was prone to friction with the relief features of land.

Wind is a major characteristic of cyclone which brings about the maximum damage. Damage is also caused due to a storm surge. Storm surge causes a temporary rise in sea level. The major cause of a storm surge is wind whereas atmospheric pressure also plays an important role. The eye is the region of low pressure. Hence the sea level rises at the centre. When this eye moves to land it combines its power with strong winds to create a storm surge which affects people living near the coast. To minimize destruction, the coasts near near the predicted areas of landfall are evacuated.

Due to continuous rapid evaporation, air becomes very moist. The combination of low pressure, warm eye along with winds give rise to this evaporation in huge quantities. The increased humidity is studied.

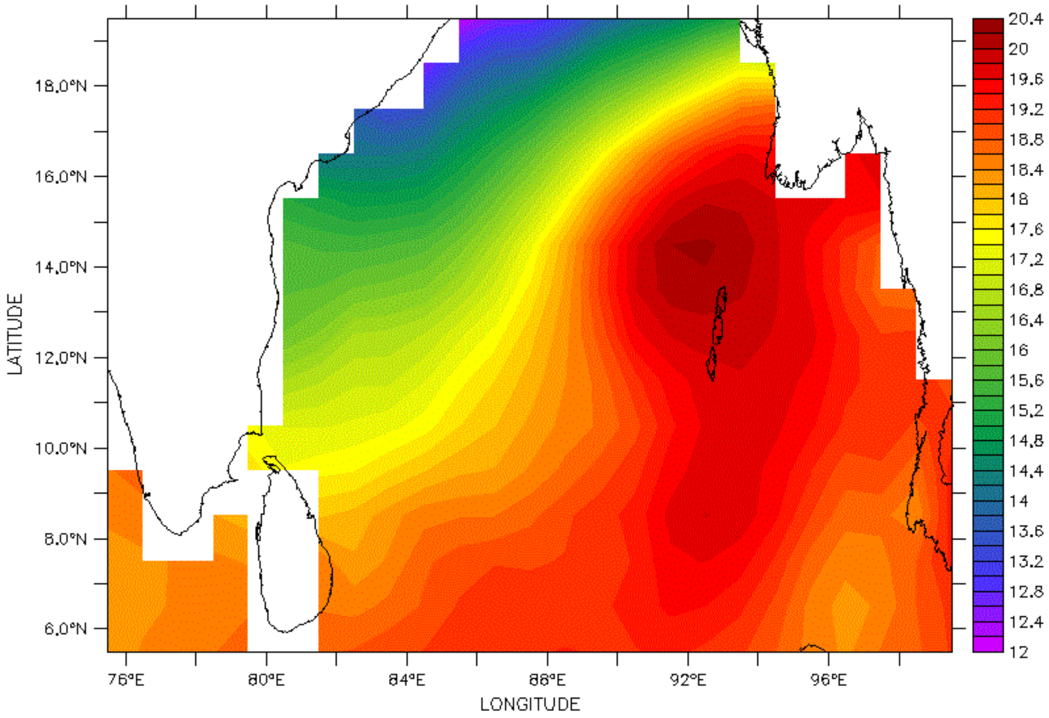
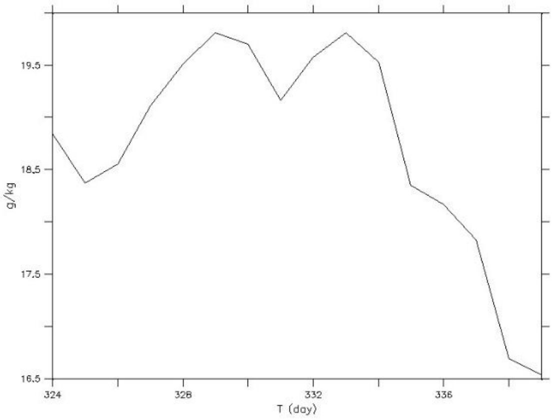


Figure 6: Humidity when the cyclone reached the Andaman and Nicobar islands

It is found that generally the humidity is highest at the region of eye. This is because the pressure is lowest near the eye. In addition, the wind also flows to the centre. Therefore the humidity near eye is more than the outlying parts. This region of humidity travels along with the eye towards land.



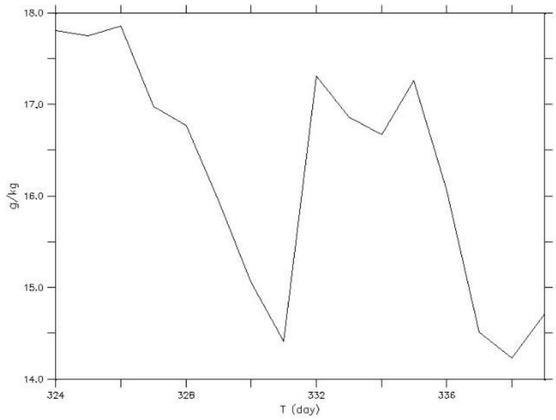


Figure 7: Plots of humidity at the Andaman crossing point (L) and the landfall point (R)

These graphs in figure 7 show that as the cyclone eye comes closer, the humidity increases due a great extent.

Since there is a huge amount of cloud formation and humidity is very high, precipitation takes place. Precipitation is one of the major issues causing a great deal of damage. Heavy precipitation causes floods. It also damages most of the crops.

The precipitation increases along with the intensity of cyclone. When the cyclone's eye pressure drops more, evaporation results in formation of clouds. When these clouds condense, precipitation occurs. The amount of precipitation therefore is proportional to the pressure drop.

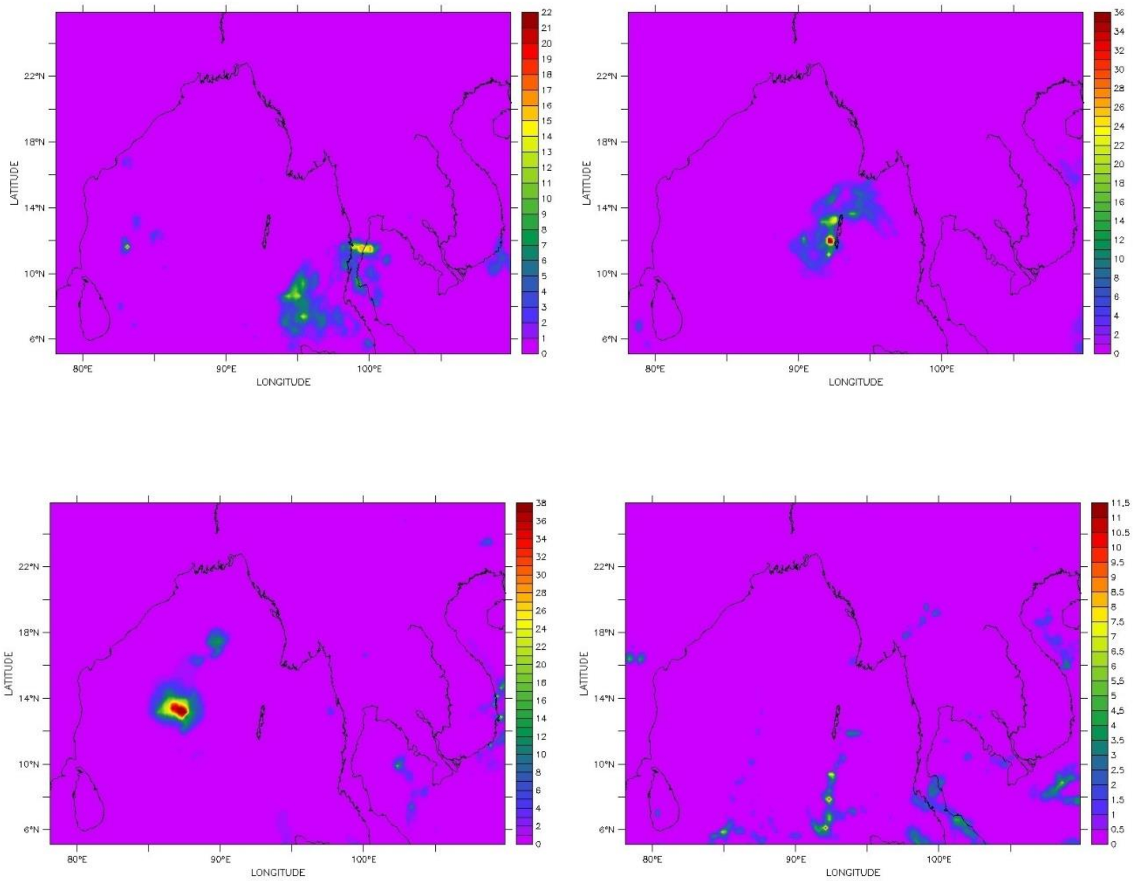


Figure 8: Precipitation patterns on 22nd (UL), 24th (UR), 26th (LL) and 28th (LR) November

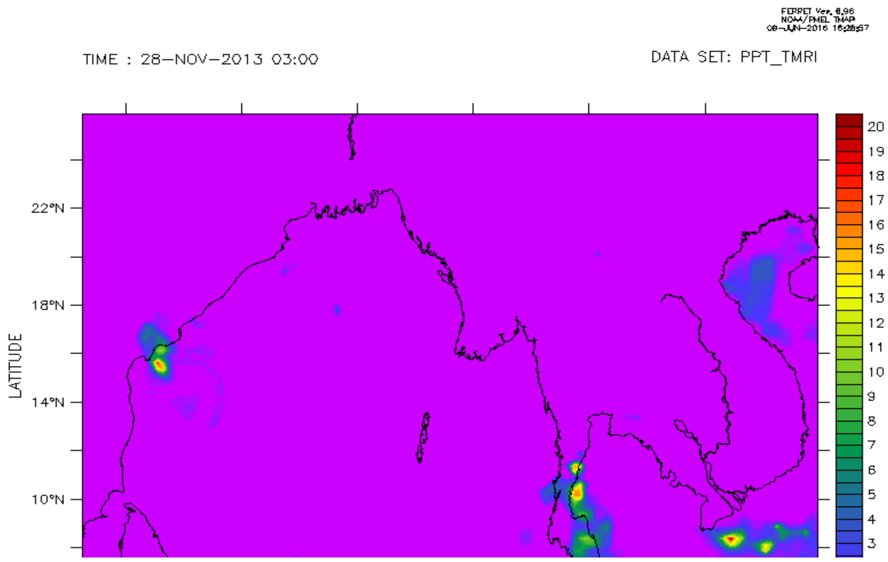


Figure 9: Precipitation during the time of landfall

Now we study how precipitation varies with time for a certain place.

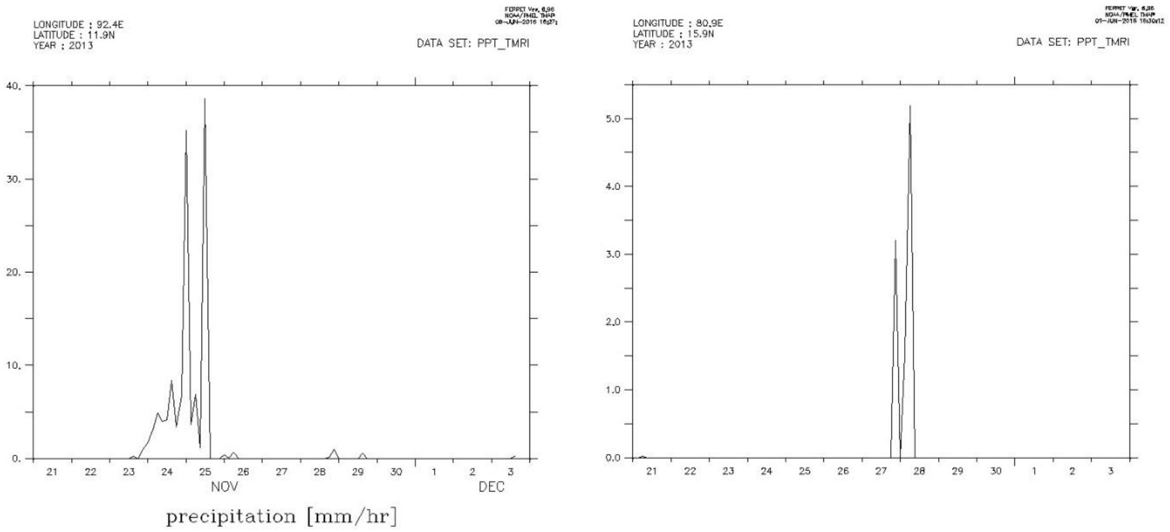


Figure 10: Precipitation plots at the Andaman crossing point (L) and the landfall point (R)

This graph in figure 10 shows that when a cyclone arrives, there is a huge amount of precipitation. But there is sudden moment of calmness in the way of the cyclone for a few hours. This is the time when the eye of the cyclone passes. The eye of a cyclone is highly humid and is of low pressure. But it is calm as no wind or precipitation occurs. The rainfall is highest near the eyewall.

ii. OCEANIC CONDITIONS:

Sea surface temperature is the most important oceanic condition affecting cyclone. A depression is formed only when the temperature of the surface layer of ocean water is at least 27 ^{0}C.

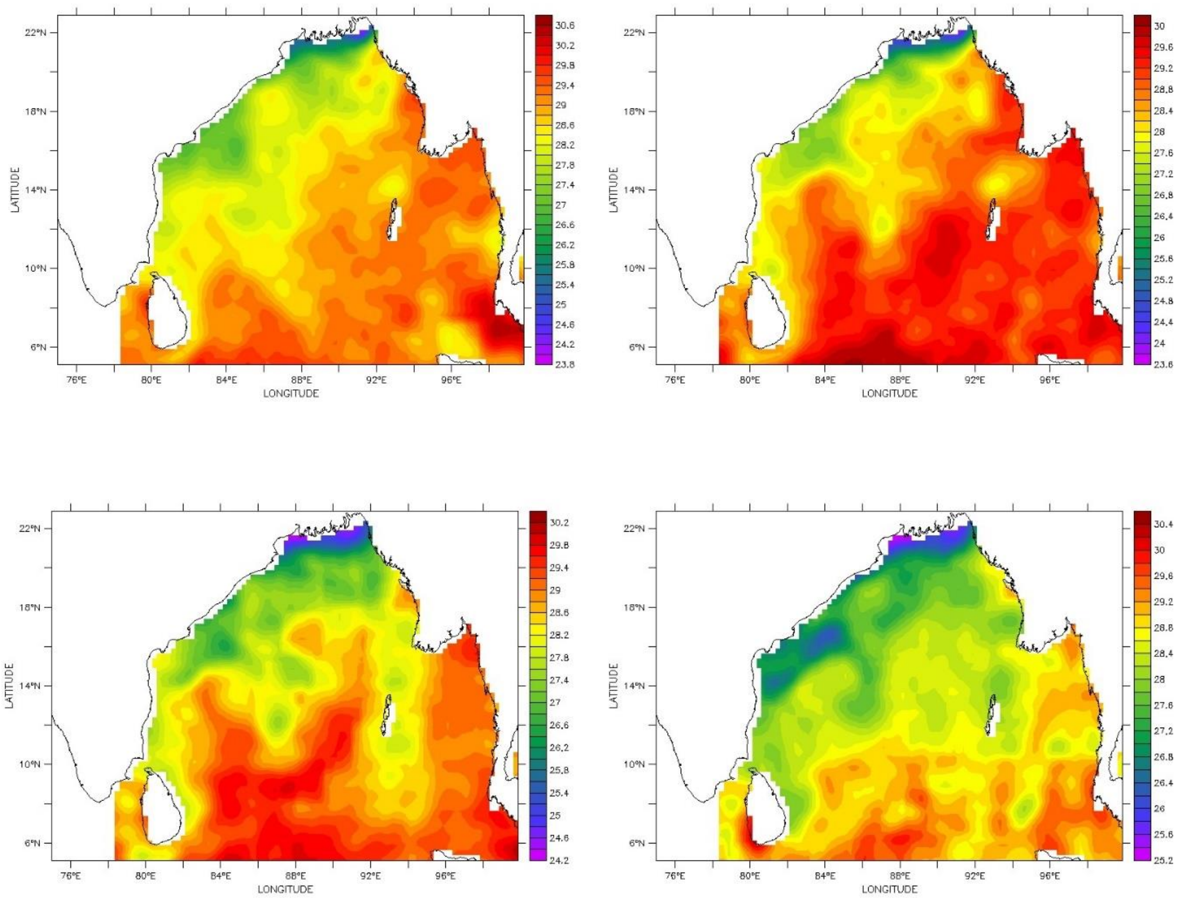


Figure 11: Sea surface temperature patterns on 22nd (UL), 24th (UR), 26th (LL) and 28th (LR) November

From these graphs in figure 12 we can see that at the place of origin of *Lehar*, the temperature rose to 30^{0}C which is very favourable for formation of a cyclone. This high SST travelled along with the eye of the cyclone. This was because the eye of the cyclone is warm. The eye can be up to 5^{0}C warmer than its surroundings. Thus SST is important in formation of cyclone.

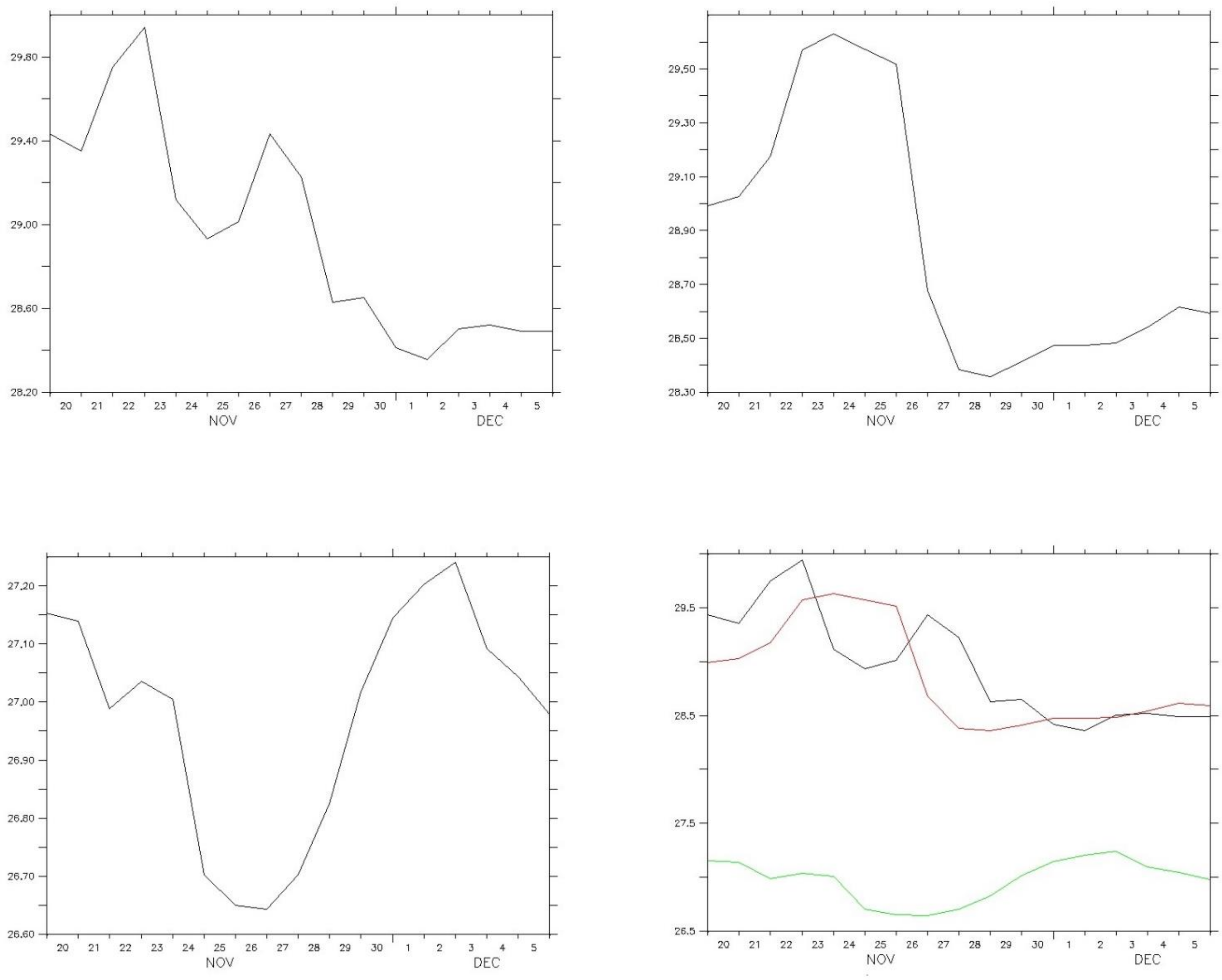


Figure 12: Sea surface temperature plots for points on the origin (UL), point of maximum strength (UR) and point of landfall (LL), and the composite of the three graphs (LR).

When a cyclone occurs, it draws up cool water from lower areas of the ocean. This phenomena is called upwelling. The water deep inside is rich in nutrients and during cyclone the nutrients are brought close to the ocean surface where insolation acts later to increase the biomass in the system. This upwelling also causes the cyclone to weaken. Cyclones which move slowly have greater amount of upwelling. Hence they weaken. This happened in case of *Lehar* cyclone. Even if though this cyclone was powerful, it had weakened by the time of landfall. Since the cyclone was moving at a slow rate, upwelling may be a cause.

The amount of nutrients received in the euphotic zone is proportional to the amount of upwelling. The nutrients after insolation gives rise to planktons and algae carrying photosynthesis using the chlorophyll a. Apart from upwelling, local mixing due to winds and rainfall also plays a secondary role. The temperature also decreases which increases the amount of air that can dissolve in water. The amount of chlorophyll a can be measured and it was studied for the time period of cyclone.

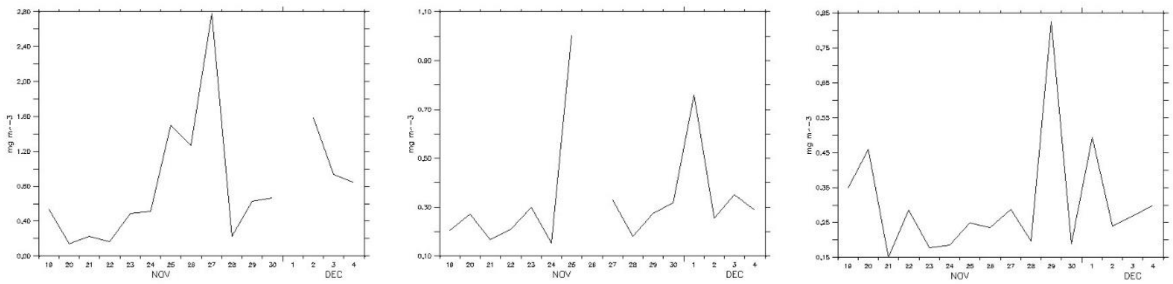


Figure 13: Chlorophyll content plots for points on the origin (L), point of maximum strength (M) and point of landfall (R)

This graph in figure 13 shows that the amount of chlorophyll increases just after the cyclone passes as it causes a lot of upwelling. Then the maximum attained chlorophyll concentration was plotted against time of the cyclone in the track and the following results were received.

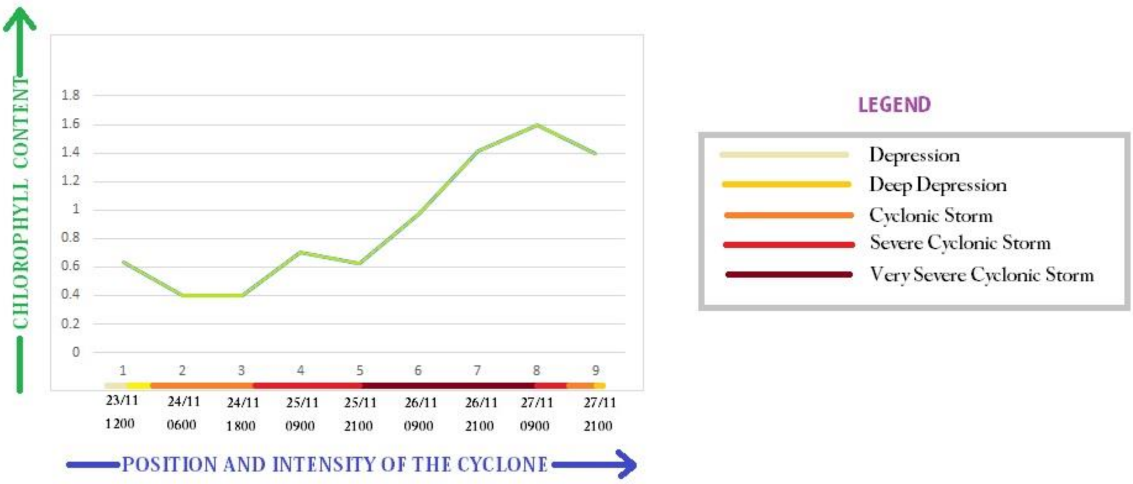


Figure 14: Maximum chlorophyll content across track of the cyclone

This plot in figure 14 shows that the amount of chlorophyll content was directly proportional to the intensity of the cyclone. Greater the intensity of the cyclone, more the upwelling which in turns increases amount of nutrients and chlorophyll concentration.

iii. THERMODYNAMICS:

A secondary method of circulation and the primary source of energy in a tropical cyclone is a Carnot's engine. The thermodynamic structure of the hurricane can be modelled as a heat engine running between sea temperature of about 300K and tropopause which has temperature of about 200K. Parcels of air traveling close to the surface take up moisture and warm, ascending air expands and cools releasing moisture (rain) during the condensation. The release of latent heat energy during the condensation provides mechanical energy for the hurricane. Both a decreasing temperature in the upper troposphere and an increasing temperature of the atmosphere close to the surface will increase the maximum winds observed in hurricanes. When applied to hurricane dynamics it defines a Carnot heat engine cycle.[18]

The following figures 15-18 will help us to analyse the thermodynamics of a cyclone.

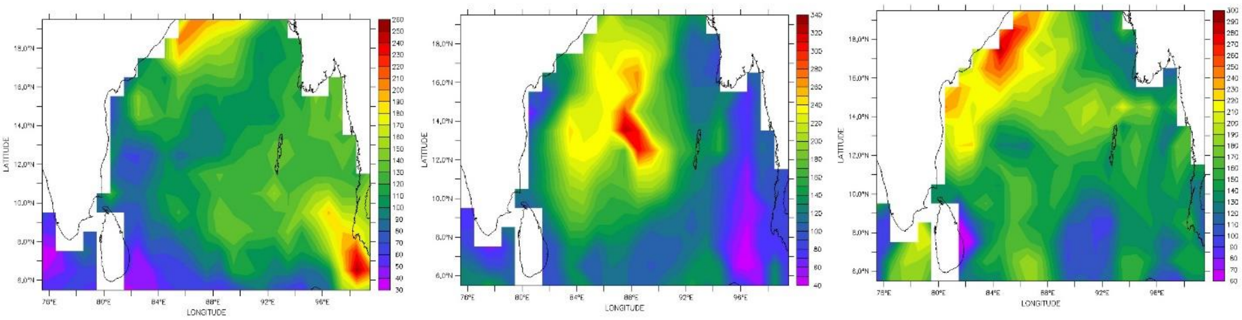


Figure 15: Latent heat distribution pattern for points on the origin (L), point of maximum strength (M) and point of landfall (R)

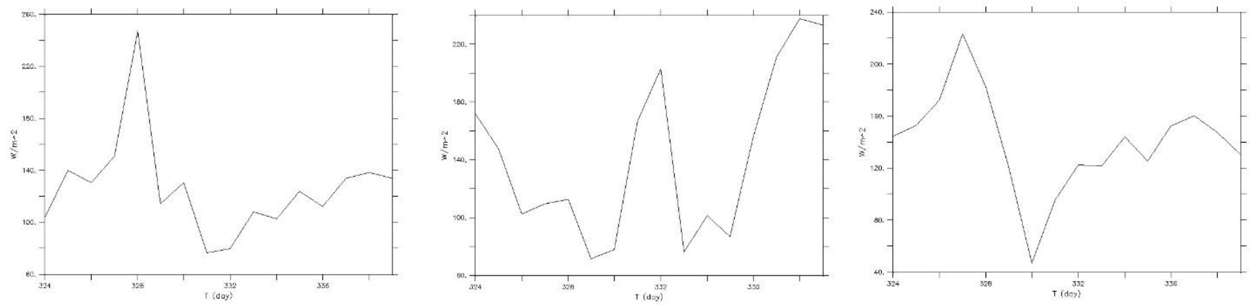


Figure 16: Latent heat plots for points on the origin (L), point of maximum strength (M) and point of landfall (R)

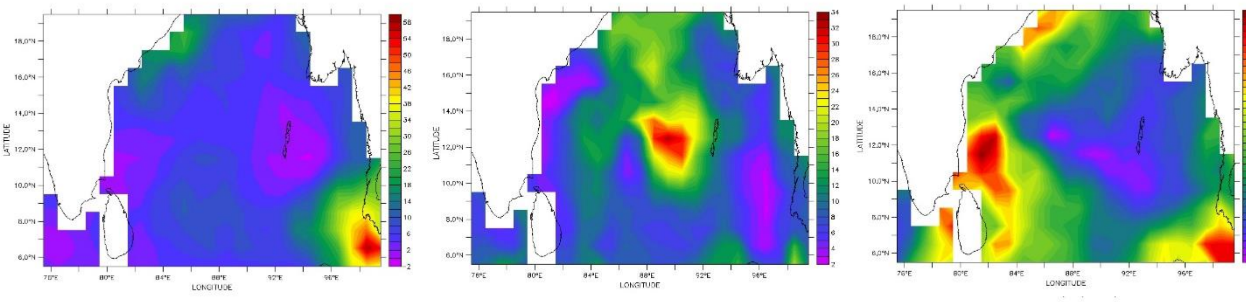


Figure 17: Sensible heat distribution pattern for points on the origin (L), point of maximum strength (M) and point of landfall (R)

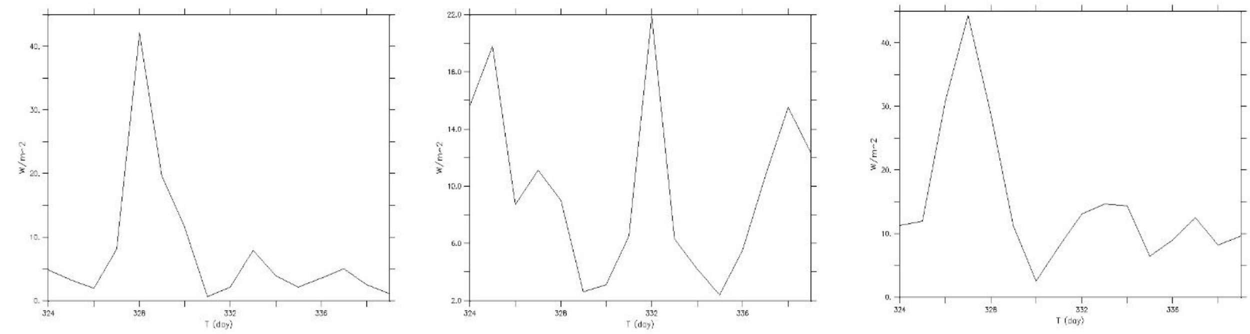


Figure 18: Sensible heat plots for points on the origin (L), point of maximum strength (M) and point of landfall (R)

Before a cyclone originates, there is a huge amount of sensible and latent heat. This heat is concentrated at a zone where the eye of the cyclone is formed. This heat travels along with the cyclone because The eye of the cyclone remains warm but continuously suffer evaporation. Nevertheless, the cyclone maintains its energy and heat is also maintained.

In the graphs we can see that heat decreases beyond normal first before increasing. This is because the eye of the cyclone is warm but its bands are way cooler due to condensation, precipitation and winds taking warm water to evaporation.

iv. CORRELATION TABLE:

Table 5: Correlation table between MetOcean parameters

FACTORS	Chl.	LH	MLD	PPT	SST	SH	QA	WS
Chl.	1	0.4447	0.8140	0.5054	-0.4072	0.3155	-0.3227	0.7141
LH	0.4447	1	-0.5642	0.7907	0.3034	0.7945	-0.8118	0.8944
MLD	0.8140	-0.5642	1	0.9892	-0.8997	-0.0157	0.3816	1
PPT	0.5054	0.7907	0.9892	1	0.0387	0.8830	-0.4526	0.8752
SST	-0.4072	0.3034	-0.8997	0.0387	1	0.2818	0.2607	-0.0506
SH	0.3155	0.7945	-0.0157	0.8830	0.2818	1	-0.4330	0.8069
QA	-0.3227	-0.8118	0.3816	-0.4526	0.2607	-0.4330	1	-0.6550
WS	0.7141	0.8944	1	0.8752	-0.0506	0.8069	-0.6550	1

This correlation table proves that all the conditions in a cyclone are significantly related to each other.

v. SHORELINE MAPPING:

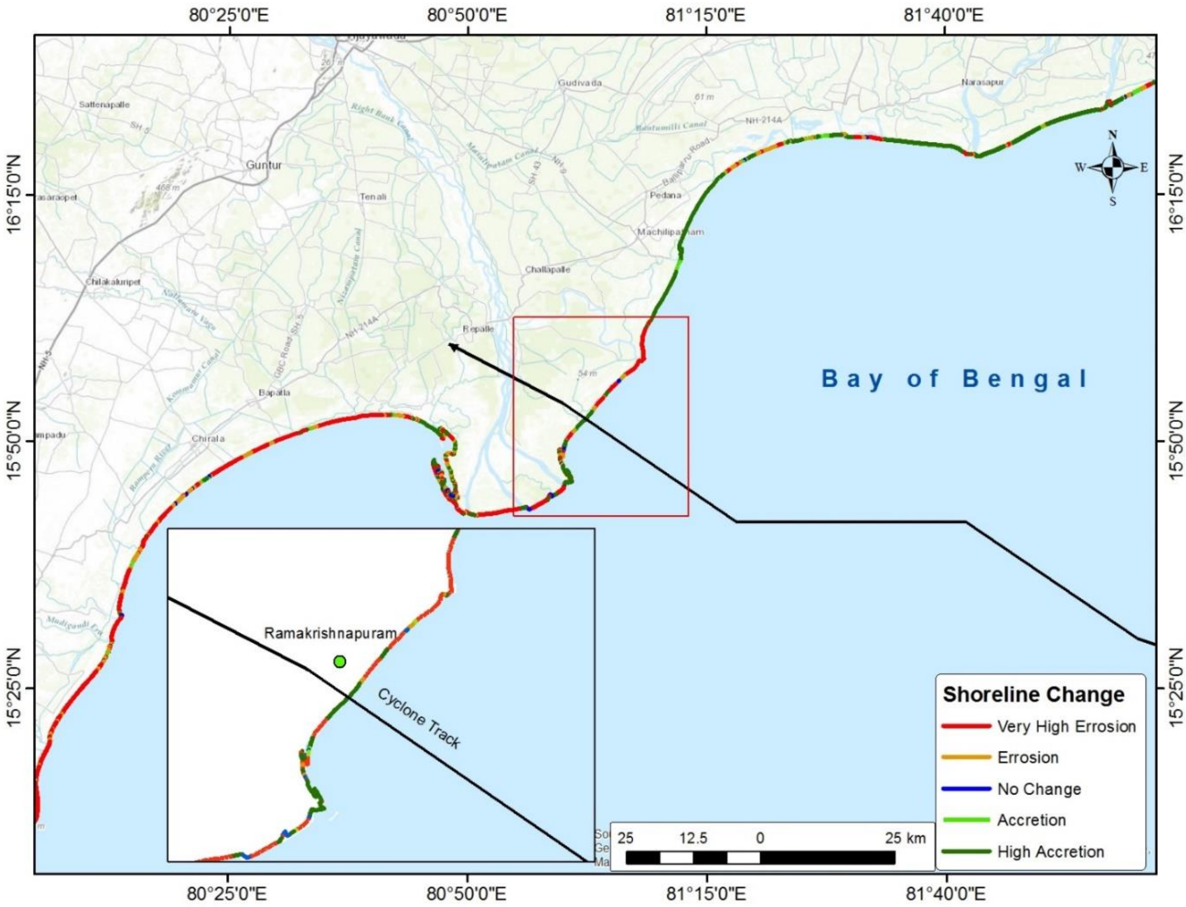


Figure 19: Map of shoreline change along with track of the cyclone

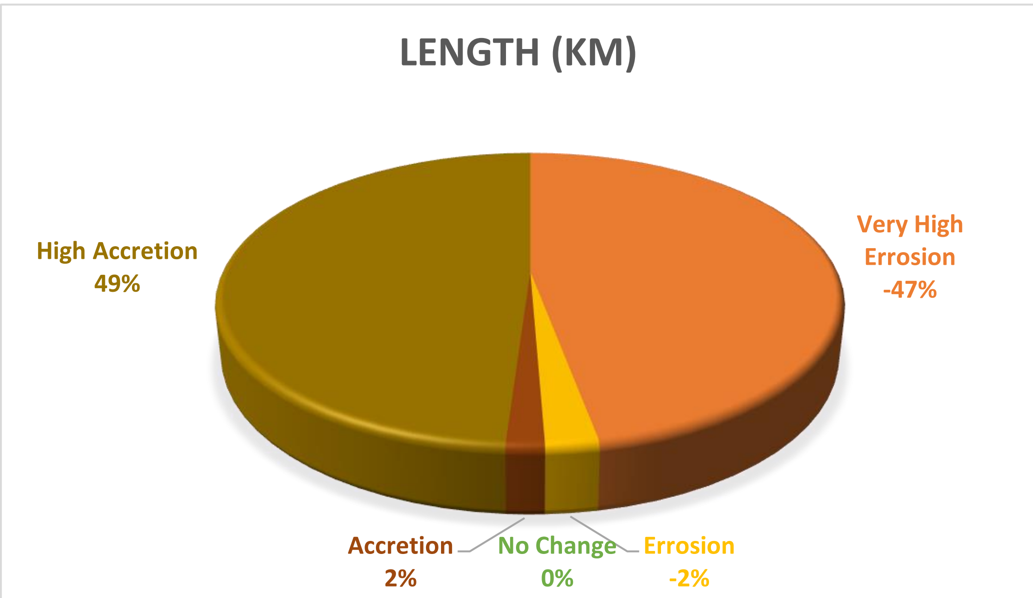


Figure 20: Amount of shoreline phenomena on the Andhra Pradesh coast

The shoreline change was mapped and assessed. When we take an area close to 25kms within the eye we get a figure which can be used for analysis. From the figure we can deduce the following:

- The area through which the eye passed did not suffer any erosion. That is because eye region is very calm and no winds or precipitation occurs in this area.
- The right side of the eye has got more affected because powerful cyclone winds attack from the right side (since the cyclone is moving anticlockwise)
- The left side suffers erosion but relatively less than the right side because the winds suffer contact with land before they reach the left shore. Contact with land weakens the winds due to heavy friction.

V. CONCLUSION

We can conclude that a tropical cyclone is a huge machine, carrying amount a lot of energy (equal to explosion of 10 megaton nuclear bomb every 20 minutes). The energy may be heat or mechanical. But this phenomena effects nearly all the MetOcean parameters up to 100 kilometres. A cyclone starts as a very simple abnormal condition but grows to become hazardous. It damages property through winds, rain and storm surge. But at the same time it increases the nutritional quality of sea and helps people harvest food. It erodes the coastline each year only to be replenished by waves later. We cannot stop a cyclone from taking place. Only we can prevent its destruction and utilize its importance. Through modelling, oceanographers and meteorologists can predict areas of landfall and radius of impact to help us. This topic is a blend of remote sensing, atmospheric and oceanic sciences.

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